THE PAST HISTORY OF THE EARTH AS INFERRED FROM THE MODE OF FORMATION OF THE SOLAR SYSTEM.

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In No. 4308 of the *Astronomische Nachrichten* (February, 1909) it is proved that the mode of formation of the solar system has been very different from that heretofore imagined by astronomers. It will, therefore, be of decided interest to physicists and geologists, as well as to astronomers and mathematicians, to consider the bearing of this new work upon the past history of the earth. If we could certainly recognize the general process by which the solar system was formed, it would of course follow that the earth, as one of the inner planets of that system, originated in the same way, and much new light might be thrown upon the problems of the physics of the globe.

The investigation outlined in the *Astronomische Nachrichten,* No. 4308, was undertaken for astronomical purposes only, and was therefore in no way biased by other considerations. And since the new method is accurate and conclusive, so as to demonstrate with all rigor the actual processes involved in the formation of our system, it becomes peculiarly valuable in throwing light upon the past history of the earth. In fact this new theory gives the only accurate and reliable data that we have on the subject, and it is difficult to see where other data of equal trustworthiness could be obtained. We shall therefore first summarize the process by which the solar system was formed, as shown by the researches in astronomy, and then apply this general theory to the past history of our particular planet.

Though Laplace was the greatest master of celestial mechanics since Newton, and formulated the nebular hypothesis as the culmination of his researches on the dynamics of our system, yet it was

TABLE SHOWING THE APPLICATION OF BABINET'S CRITERION TO THE PLANETS AND SATELLITES WHEN THE SUN AND PLANETS ARE EXPANDED TO FILL THE ORBITS OF THE BODIES REVOLVING ABOUT THEM.

Solar System.

Planet.	R_0 The Sun's Observed Time of Rotation.	P_0 Observed Period of Planet.	R_c Time of Sun's Rotation Calculated by Babinet's Criterion.
Mercury	25.3 days = 0.069267 yrs.	0.24085 yrs.	479 yrs.
Venus		0.61237 "	1673 "
The earth		1.00000 "	3192 "
Mars		1.88085 "	7424 "
Ceres		4.60345 "	24487 "
Jupiter		11.86 "	86560 "
Saturn		29.46 "	290962 "
Uranus		84.02 "	1176765 "
Neptune		164.78 "	2888533 "

Sub-systems.

Planet.	Satellite.	R_0 Adopted Rotation of Planet.	P_0 Observed Period of Satellite.	R_e Time of Planet's Rotation Calculated by Babinet's Criterion.
The earth	The moon	1 day	27.32166 days	3632.45 days
Mars	Phobos	$24^h.62297$	7.6542 hours	190.62 hours
	Deimos		30.2983 "	1193.52 "
Jupiter	V	$9^h.928$	11.9563 "	64.456 hours
	I		1.7698605 days	14.60 days
	II		3.5540942 "	35.900 "
	III		7.1663872 "	93.933 "
	IV		16.7535524 "	290.63 "
	VI		250.618 "	10768.8 "
	VII		265.0 "	11602.4 "
	VIII		930.73 "	61997.1 "
Saturn	Inner edge of ring	$10^h.641$	0.236 "	0.6228 days
	Outer edge of ring		0.6456 "	2.383 "
	Mimas		0.94242 "	4.2902 "
	Enceladus		1.37022 "	7.0615 "
	Tethys		1.887796 "	10.822 "
	Dione		2.736913 "	17.751 "
	Rhea		4.517500 "	34.620 "
	Titan		15.945417 "	186.05 "
	Hyperion		21.277396 "	273.06 "
	Iapetus		79.329375 "	1580.1 "
	Phœbe		546.5	20712 "
Uranus	Ariel	$10^h.1112$ (Cf. A. N., 3992)	2.520383 "	33.714 "
	Umbriel		4.144181 "	65.435 "
	Titania		8.705897 "	176.05 "
	Oberon		13.463269 "	314.83 "
Neptune	Satellite	$12^h.84817$ (Cf. A. N., 3992)	5.87690 "	141.8 "

reserved for Babinet of Paris to point out[1] a rigorous mechanical law which enables the mathematician to test the nebular hypothesis. Nevertheless, Laplace himself constantly uses the same principle, in the law of the conservation of areas, though he does not apply it to the development of our system. The principle involved is that of the constancy of the moment of momentum of axial rotation. According to this law, we have

$$C = \sum mr^2\omega = \omega\sum mr^2 = \omega'\sum mr'^2, \qquad (1)$$

where r is the radius of the rotating globe, ω the angular velocity of rotation, and C a constant; while r' and ω' are the corresponding quantities at some other epoch. Thus at any two epochs, however much the freely rotating globe may have changed by contraction or expansion, we always have

$$\omega' r'^2 = \omega r^2. \qquad (2)$$

By taking accurate values of the radii and rotation-periods of the sun and planets as now observed, we may calculate the corresponding rotation-periods when the globes are imagined expanded to fill the orbits of the planets and satellites. The accompanying table gives the most important data for the solar system.[2]

It will be found from this table that the sun would have rotated with extreme slowness if it had been expanded to the orbits of the several planets, and the planets also would have rotated very slowly if they had been expanded to fill the orbits of their satellites. The difference between the observed periods of revolution and the calculated periods of rotation is so great that we readily see that the planets could never have been detached from the sun, and the satellites could never have been detached from the planets, by acceleration of rotation as imagined by Laplace. It is evident, therefore, that all of these bodies have been captured or added from without, and have had their orbits reduced in size and rounded up under the secular action of the nebular resisting medium formerly pervading the planetary system.

Ever since the time of Laplace it has been believed that our

[1] *Comptes Rendus*, Tome 52, p. 481, March 18, 1861.

[2] Cf. *Astron. Nachr.*, no. 4308.

system was formed from a nebula, and to-day we know that this nebula was of the spiral type, due to the automatic coiling up under mutual gravitation of two or more streams of cosmical dust. Wherever such streams meet, or pass near one another, there is developed a cosmical vortex, with rotation about a center, and a definite moment of momentum about an axis. This is due to the fact that the impact is never central, but always unsymmetrical, and thus gives rise to a rotation.

The two or more streams which meet continue to wind up, under the effects of mutual gravitation, and thus we have the different observed types of spiral nebulæ. The nebula continues to rotate and the coils are drawn closer and closer together, and the whole mass slowly settles towards its center. The planets, which are formed by the agglomeration of cosmical dust in the convolutions of the nebula, revolve constantly in the surrounding nebular medium. As the planetary bodies grow by the gathering in of the cosmical dust in which they revolve their orbits are reduced in size and rounded up under the secular action of the resisting medium.

It is shown by this line of inquiry, and especially by the roundness of Neptune's orbit, that our system extends much beyond Neptune; and that the orbits now observed to have a round form were originally much larger and also much more eccentric than they are now seen to be. It is impossible to determine definitely how much the orbits have been reduced in size, but owing to the almost total obliteration of the eccentricity, it seems certain that they were originally two or three times larger than they are now.

Moreover, it is proved that in a resisting medium of given density the secular effect is proportionally greater on a small planet than on a large one. This is owing to the fact that the mass, and therefore the moment of momentum, is proportional to the cube of the planet's radius, but the surface, and therefore the resistance of the medium, proportional to the square of the radius; so that the changes in the orbit of a small body are greater than in that of a large body in the inverse ratio of the radius, for masses of the same mean density.

Accordingly it follows that small planets, such as the asteroids or inner planets were at a former epoch, when revolving in a

nebula, have a tendency to settle towards the center more rapidly than large planets. In our system the asteroids have been gathered into their present position partly by the effects of resistance, and partly by the disturbing action of Jupiter, which throws them into the stable region within his orbit. When the paths of the asteroids cross his orbit, the motion is shown to be unstable, and therefore such overlapping orbits are temporary and not permanent.

It follows, therefore, that the orbit of the earth was originally much larger and much more eccentric than at present. The earth may have begun to form almost as far away as Jupiter's orbit, or even beyond it. In time the primordial earth was thrown within that orbit, where the asteroids now revolve. Thus the earth revolved in safety and continued to grow by gathering up more and more cosmical dust. The history of Mars was similar. The major axis of the orbit was decreased by the effects of resistance, and at the same time the eccentricity steadily diminished, till we have the planets as they are to-day. This is as certain as anything can be, and it throws an interesting light on the past history of our earth. While the information thus given us is meager, it is, so far as I know, our only means of fathoming the mystery which has always surrounded the origin of our planet.

We may therefore say that in the beginning the earth was a small body like one of the asteroids; it then revolved in a much larger and more eccentric orbit than at present, and was augmented gradually by the sweeping up of cosmical dust in its ceaseless motion around the sun. In general, this process of building up the earth was excessively slow, though at times the motion through streams may have given larger additions of matter; but the full process may have occupied a billion years. Of course, geological history began only after the earth had attained about its present dimensions. And the study of the crust of the globe shows that no large additions to the matter of our planet have been made since geological history began. The sedimentary rocks are not filled with any considerable amount of meteoric matter precipitated from the heavenly spaces.

From these considerations it follows that the earth was built up very gradually by accretion; and that this growth took place because our globe was revolving in a resisting medium made up of

fine cosmical dust. In the later periods of the earth's history, the medium has been so rare that but little matter has been added to our globe; so that not only is the whole history very long, but the latter part longer than the earlier part, as measured by the accretion then going on. In other words, the accretion now taking place is so slow as to give us by calculation, based on the observed rate, an exorbitant age of the earth; while that once going on was so large as to give too short a duration for the genesis of our planet. All estimates on the age of the earth must therefore be subject to a wide margin of uncertainty. But we may feel entirely confident that we have at length recognized the true process by which the earth was formed.

There is, however, a modifying cause which should be taken into account, in our final judgment of the process involved. It cannot be assumed that the sun was of its present mass at the start; on the contrary, we must suppose this mass to have steadily increased. The result of the augmentation of the sun's mass would be a decrease in the length of the year. Thus while the resisting medium reduced the major axis and eccentricity of the planetary orbits, the growth of the sun's mass also shortened the periodic times, without, however, decreasing the mean distance of these masses to any appreciable extent.[3]

In the actual history of our system, these two causes have therefore conspired together and the results now observed must be ascribed to both causes combined. If we wish to inquire at what rate a change of a given percentage in the sun's mass would affect the length of the year, we may proceed as follows. By a well known law for circular motion we have

$$M + m = \frac{4\pi^2 a^3}{t^2}. \tag{3}$$

If we differentiate this expression, considering M and t alone to be variable, we shall get

$$dM(t^2) + (M + m)2tdt = 0,$$

or

$$\frac{dM}{M + m} = -\frac{2dt}{t}. \tag{4}$$

[3] Cf. Laplace, "Mécanique Celeste," Liv. X., Chap. VII., § 21.

This simple expression shows that a change of a given percentage in M produces a contrary change half as large in t. In other words, if the sun's mass be *increased by one per cent.*, the length of the year will thereby be *decreased by two per cent.* Thus in the lapse of ages the augmentation of the sun's mass may have shortened the periods of the planets very materially; and this would slightly decrease their mean distances, as in the case of the resisting medium. Nevertheless, a gradual change in the sun's mass would not affect the eccentricity as it does the major axis.

Accordingly the small size and round form of the planetary orbits must be explained mainly by the secular effects of the resisting medium formerly pervading our system. And as the earth has been formed by accretion, and not at all by detachment from the sun, as supposed by Laplace, it follows that the matter of the globe is essentially of the same character throughout. For we have elsewhere shown that friction and resistance to motion in the body of our globe would prevent the heavier elements from separating from the lighter ones. So that the old theories which ascribe an iron nucleus to the earth must be given up as unjustifiable and misleading. And the increase of density, rigidity, and temperature towards the center is due principally to the pressure of the superincumbent matter upon the layers confined within. It is this pressure which gives the globe its great effective rigidity. If the pressure were relieved, the imprisoned matter, which now behaves as solid, would expand as vapor, owing to the high temperature still existing within the globe.

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ADDENDUM ON THE VIEWS OF EULER, 1749.

Euler's Remarks on the Secular Effects of the Resisting Medium upon the Orbital Motion of the Earth, and on the Origin of the Planets at a Great Distance from the Sun.

In view of the results briefly indicated in *Astronomische Nachricten,* No. 4308, and of the paramount part played by the resisting medium in shaping the orbits of the planets and satellites, as well as the orbits of the attendant bodies in other cosmical systems observed in the immensity of space, some remarks of the celebrated Leonard Euler are of much interest to contemporary astronomers and mathematicians. These remarks are included in the *Philosophical Transactions of the Royal Society* for 1749, pp. 141–142, under the title: "Part of a Letter from Leonard Euler, Professor of Mathematics at Berlin and F.R.S., to the Rev. Mr. Caspar Wetstein, Chaplain to the Prince of Wales, dated, Berlin, June 28, 1749; read November 2, 1749." And this is followed by a similar extract from a second letter to Wetstein, dated, Berlin, December 20, 1749, read March 1, 1750.

The views of Euler here set forth are very remarkable not only for the insight they show into the mechanism of the heavenly motions, but also into the true mode of origin of our solar system. It must be remembered that, in reaching these views on cosmogony, Euler preceded both Kant (1755) and Laplace (1796), and that he was the first mathematician since Newton to consider the secular effects of a resisting medium. His views on the origin of the planets are therefore free from every possible prejudice, and the direct outcome of the continued action of forces which he believed to be operative in the heavenly spaces.

Newton seems to have held that the spaces where the planets move are essentially as devoid of matter as a vacuum. This is expressly stated in first paragraph of the General Scholium to the "Principia." Yet he may have believed that some waste matter is diffused in the celestial spaces, for in the paragraph just before the General Scholium, he says:

The vapors which arise from the sun, the fixed stars, and the tails of the comets may meet at last with, and fall into, the atmosphere of the planets by their gravity.

Cheseaux was the first to express the view that the heavenly spaces are not perfectly transparent, but that light suffers a certain amount of absorption or extinction in passing over great distances. (Cf. L. de Cheseaux, "Traité de la Cométe qui a paru en 1743 et 1744," 8°, Lusanne & Geneva, 1744, p. 223.) This account of Cheseaux was written five years before the promulgation of Euler's views, and it is uncertain to what extent, if at all, Newton and Cheseaux had influenced Euler in reaching the conclusion that the planets suffer resistance in their motion about the sun.

The extracts from Euler's letters are as follows:

1. *First Letter:*

XXII. Monsieur le Monnier writes to me that there is, at Leyden, an Arabick manuscript of Ibn Jounis (if I am not mistaken in the name, for it is not distinctly written in the letter), which contains a history of Astronomical observations. M. le Monnier says, that he insisted strongly on publishing a good translation of that book. And as such a work would contribute much to the improvement of Astronomy, I should be glad to see it published. I am very impatient to see such a work which contains observations, that are not so old as those recorded by *Ptolemy*. For having carefully examined the modern observations of the sun with those of some centuries past, although I have not gone further back than the 15th century, in which I have found *Walther's* observations made at Nüremberg; yet I have observed that the motion of the Sun (or of the Earth) is sensibly accelerated since that time; so that the years are shorter at present than formerly; the reason of which is very natural, for if the earth, in its motion, suffers some little resistance (which cannot be doubted, since the space through which the planets move, is necessarily full of some subtile matter, were it no other than that of light), the effect of this resistance will gradually bring the planets nearer and nearer the sun; and as their orbits thereby become less, their periodical times will also be diminished. Thus in time the earth ought to come within the region of Venus, and in fine into that of Mercury, where it would necessarily be burnt. Hence it is manifest that the system of the planets cannot last forever in its (present) state. It also incontestibly follows that this system must have had a beginning; for whoever denies it must grant me, that there was a time, when the earth was at the distance of Saturn and even farther, and consequently that no living creature could subsist there. Nay there must have been a time when the planets were nearer to some fixt stars than to the Sun; and in this case they could never come into the solar system. This then is a proof, purely physical, that the world in its present state, must have had a beginning, and

must have an end. In order to improve this notion, and to find with exactitude how much the years become shorter in each Century; I am in hopes that a great number of older observations will afford me the necessary succours.

2. *Second Letter:*

XXIII. I am still thoroughly convinced of the truth of what I advanced that the orbs of the planets continue to be contracted, and consequently their periodic times grow less. . . . The late Dr. Halley has also remarked that the revolutions of the moon are quicker at present than they were in the time of the ancient Chaldeans, who have left us some observations of Eclipses.

Euler then discusses the difficulty of finding the number of days since the time of Ptolemy, and thinks the uncertainty may be a day or two, also raises the question whether the length of the day is constant.

At present we measure the length of the day by the number of oscillations which a pendulum of given length makes in this space of time; but the ancients were not acquainted with these experiments, whereby we might have been informed, whether a pendulum of the same length made as many vibrations in a day as now. But even though the Ancients had actually made such experiments, we could draw no inferences from them, without supposing, that gravity on which the time of an oscillation depends, has always been of the same force; but who will ever be in a condition to prove this invariability in gravity?

He finally concludes that both the lengths of the year and day are diminishing, "so that the same number will answer nearly to a year."

The views of Euler here set forth that the earth and other planets were at one time farther from the sun than at present are so remarkable that it is scarcely necessary to do more than bring them to the attention of astronomers.

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